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An Ignition Torch Based on Photoignition of Carbon Nanotubes at Elevated Pressure

(patent pending)

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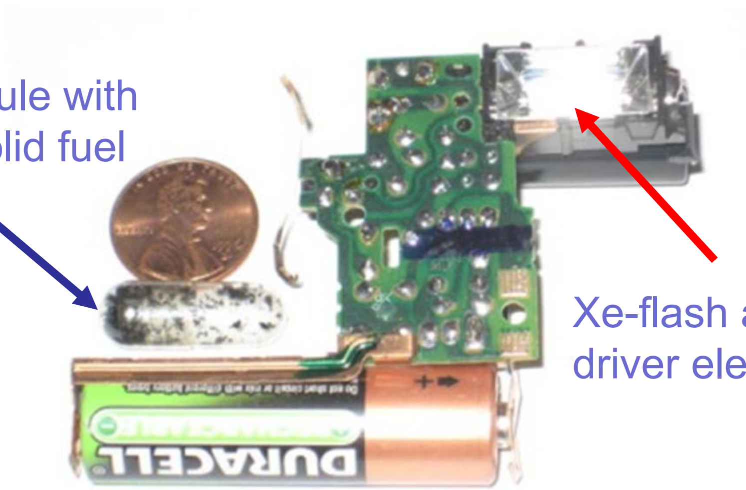
Background

- The source of high pressure in most combustion devices is the combustion
  - Ignition occurs at low pressure
- A research project at AFRL required ignition to occur while already at high pressure
  - Conventional spark ignition is unreliable at high pressure
  - Alternatives such as laser ignition were impractical
- The solution was a Photoignition Torch (PITCH)
  - PITCH is also electromagnetically quiet, and doesn’t interfere with instrumentation like spark ignitors do.

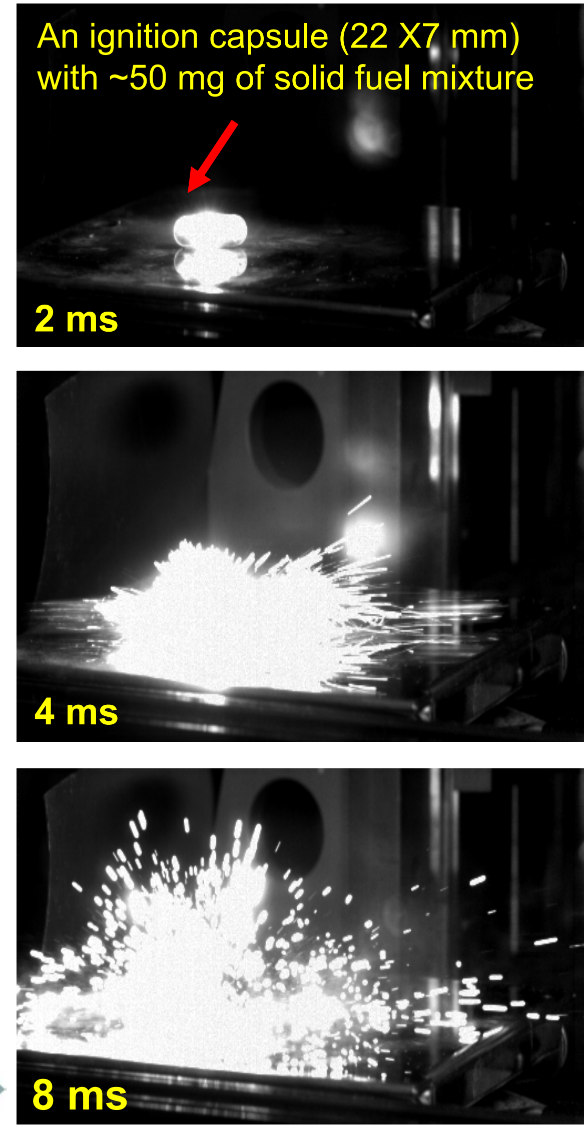
Photoignition of Nanostructured Solid Fuels by a Camera Flash

The photoignition torch (PITCH) uses a Xe-flash to create a spray of burning particles for initiation of combustions by utilizing ignition properties of carbon nanotubes (CNT)

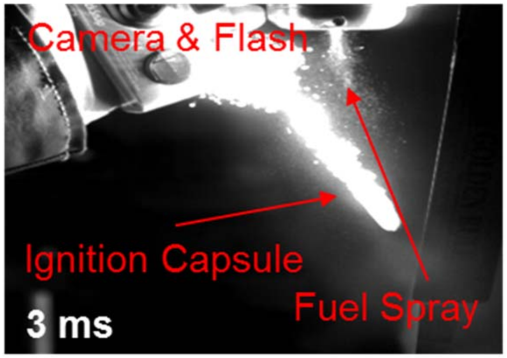


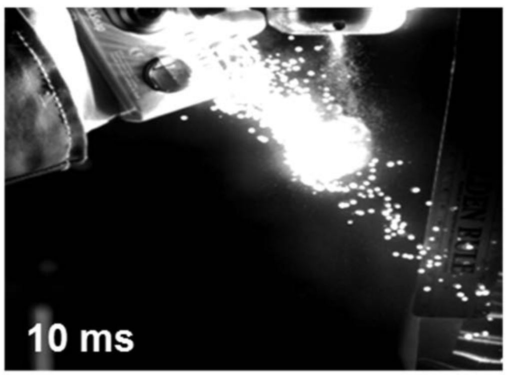
Top: The complete hardware of a self-contained PITCH. The ignition capsule contains ~50 mg of solid fuel mixture of CNT and solid rocket propellants. PITCH is based on proven technologies that have been in use for decades in rocket industry.

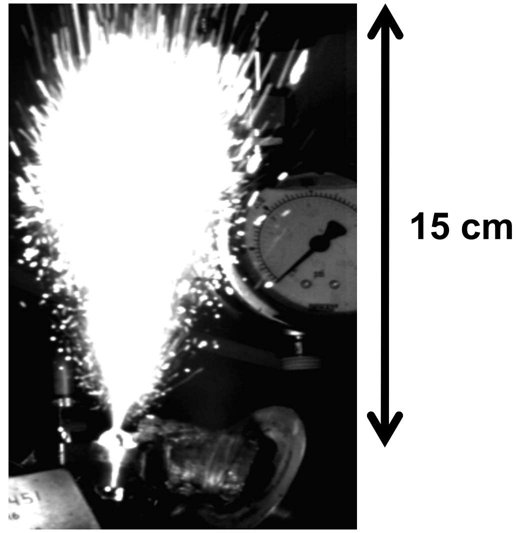
Right: Photoignition of an encapsulated solid fuel mixture moments after the camera flash fires.



Photoignition Torch for Fast, Robust, and Scalable Ignition







TOP: A 15 cm jet of hot particles that last 30-300 ms

LEFT: Snapshots of a photoignition torch as it ignites an RP-2 fuel spray

RIGHT: Movie of a 50 mg ignition torch that is captured at 2000 fps and shown at 20 fps Click to play >>>

How PITCH Works?

- PITCH takes advantage of photo ignition properties of single wall carbon nanotubes (SWNT) that is only a small faction of the fluence needed for the laser ignition
- While other materials show photoignition property SWNT shows a low enough minimum ignition energy (MIE) with a good burns temperature
- For a PITCH we use SWNT along with other energetic materials that is referred to as photoignition solid fuel mixture (SFM)

Nanoparticle Samples	**Particle Size/ Smallest Dimensional Size**	**Min. ignition Energy/area, Fluence (mJ/cm^2)**	**Ignition/burn Temperature* (^0C)**
SWNT(51% Fe)	< 30 nm	64 ± 8	490 ± 30
SWNT(18% Fe)	< 30 nm	182 ± 13	420 ± 50
Graphene Oxide Foam/Nanoplatelets	< 30 nm thick platelets	500 ± 60	370 ± 100
Al-nanoparticles	~18 nm	290 ± 50	1100 ± 150
Fe, Carbon coated	~ 40 nm	220 ± 35	250 ± 30
Fe powder	~ 30 nm	150 ± 25	220 ± 30
Pd powder	~ 12 nm	530 ± 60	320 ± 40

MIE for different nanostructured materials and their burn temperatures

*Temp. of a focused spot on the surface of the sample that is ~ 2 mm in diameter

Content of Solid Fuel Mixtures

	CNT, PI Agent (Wt%)	Fuel Al_NP (Wt%)	Fuel SRF* (Wt%)	Oxidizer B-KNO_3 (Wt%)	Oxidizer $KMnO_4$ (Wt%)	Observations and Comments On the Relative Effects of Additives
1	~3%		~97%			*solid rocket fuel (SRF) ignition is unreliable due to ignition delays (ratio doesn't matter)
2	10%				90%	Reliable ignition only $\gtrsim$10 atm with a short burn duration, low gas pressure
3	10%			90%		Improved ignition reliability & burn Temp. compared to the above
4	3%	7-12%	85-90%			More reliable ignition, burns at higher Temp. & generates more gas than samples 2 & 3
5	3%	7%	45%		45%	Less reliable ignition than the above unless the chamber Pres. $\gtrsim$10 atm
6	3%	7%	50%	40%		Improved flash sensitivity & ignition + generate a lot of gas & smoke
7	**1%**	**9%**	**80%**	**10%**		**Best ignition sensitivity, reliability & burn duration for Cham. Pres. $\gtrsim$7 atm**
8	2%	8%	70%		20%	Good for chamber Pres. $\gtrsim$15 atm
9	2%	8%	70%	20%		Improved reliability and burn duration than #8
10	1%	15%	75%	9%		As good as the above at atmospheric pressure, but burns too fast $\gtrsim$ 15 atm

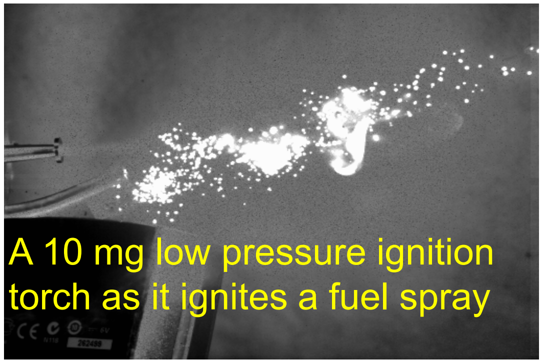
PITCH for Specific Ignition Applications

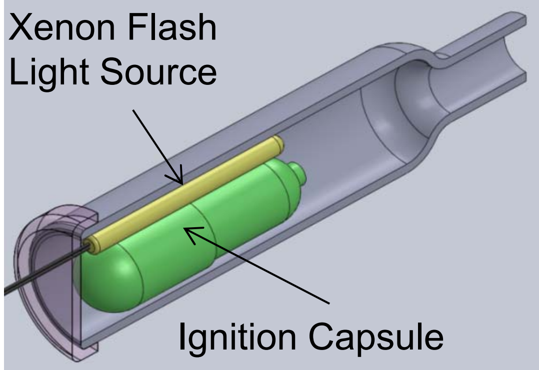
PITCH provides certain advantages over spark ignition systems for rocket engines and combustors:

- PITCH operates within a wide range of pressures and its reaction time (<40 ms) decreases with increased pressure
- It produces no electromagnetic interference (EMI)
- PITCH is photo-activated directly or via an optical fiber so it is not affected by EMI or ESD
- It is self-contained and lightweight using one AA battery

PITCH also offers unique ignition capabilities in combustor research and development applications:

- Ignition at target pressure, avoiding potential overheating during pressure ramp-up.

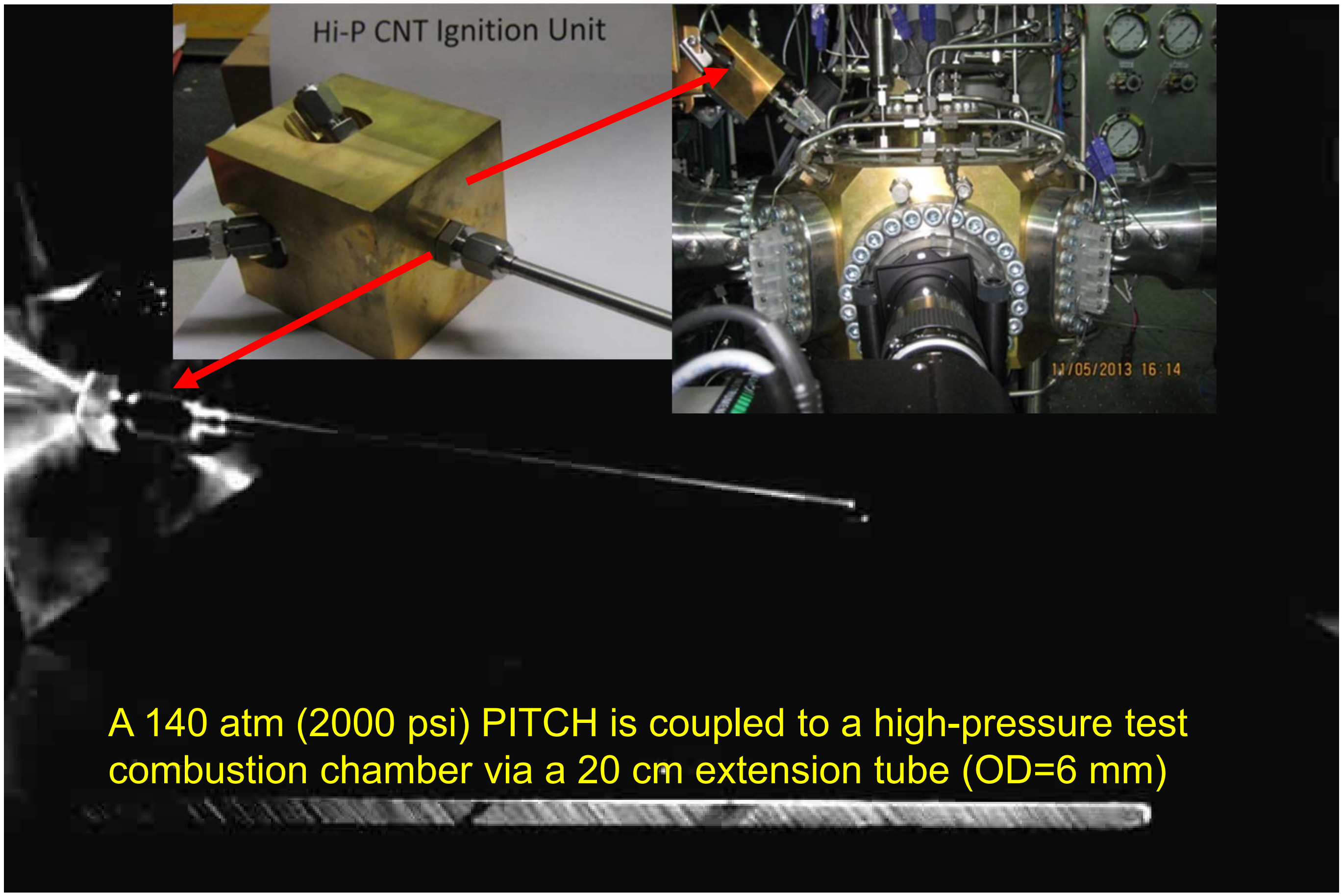




The schematic image of high pressure ignition torch with a remotely operated Xe-flash lamp

We use PITCH to ignite subscale test rockets at 130 K and ~35 atm (~500 psi) to study potentially destructive CI effects for <3 s, while avoiding overheating

High Pressure PITCH Applied to a H_2/O_2 Subscale Rocket Injector



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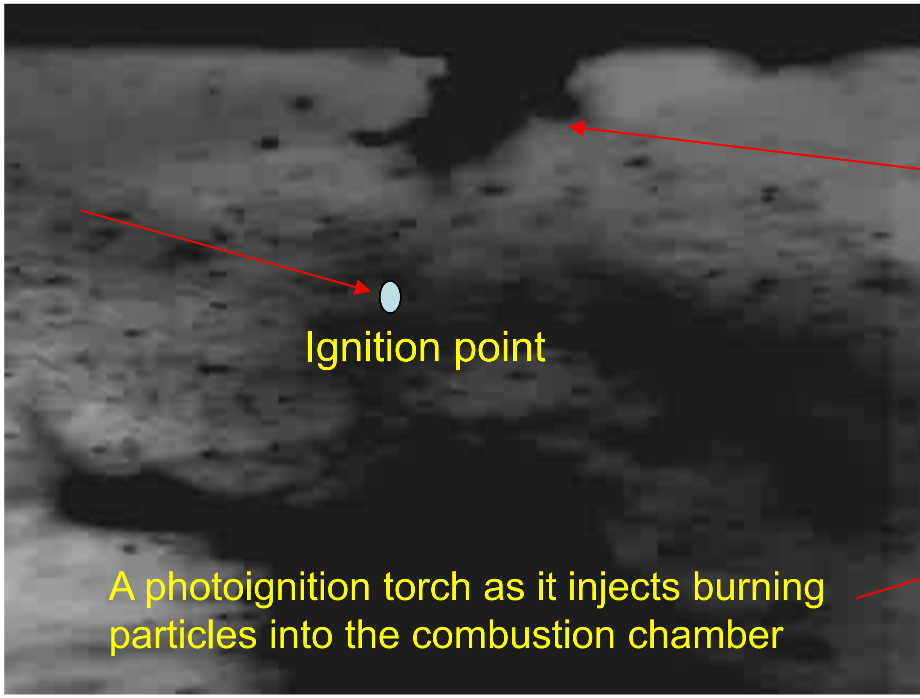
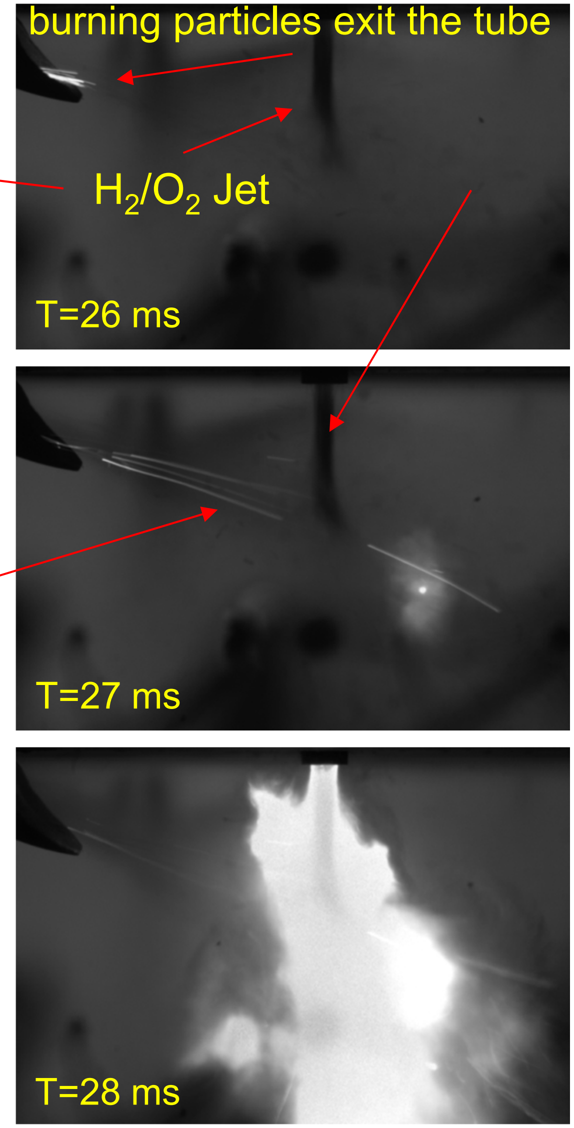
Top: a high-pressure chamber for test of subscale rocket injector and its ignition torch

Bottom: Movie of a 140 atm (2000 psi) PITCH (top left corner) emitting burning particles.

High Pressure PITCH Applied to an H_2/O_2 Subscale Rocket Injector





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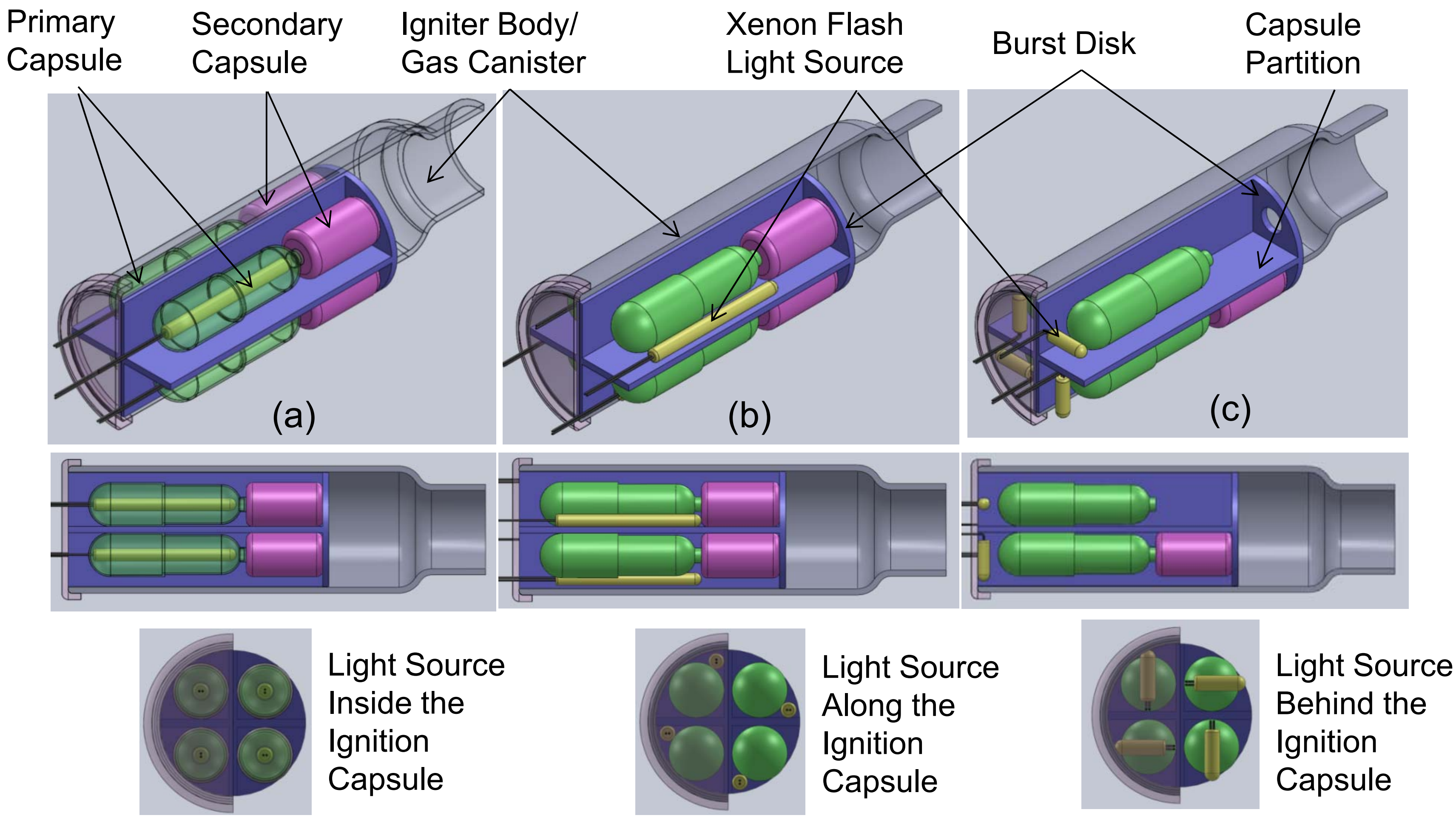
Top: A movie of a high-pressure ignition torch igniting a 130 K H_2/O_2 coaxial jet at 35 atm. The arrow shows the trajectory of the hot particle that causes the ignition

Right: Snapshots of combustion in H_2/O_2 coaxial jet that was ignited by a PITCH. The combustion was achieved within 25-30 ms after the Xe-flash fires.

High Pressure PITCH With Multiple Ignition Capability

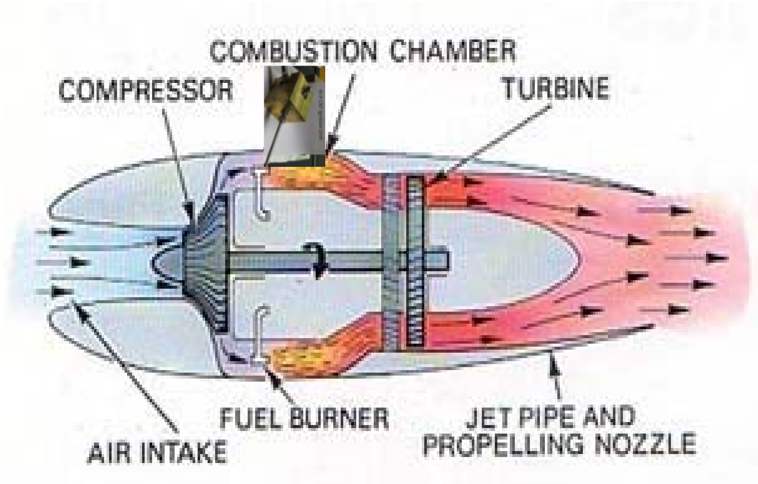


Different configurations for placement of Xe-flashes in a PITCH in high pressure canisters offer multiple ignitions. Burst disks allow each section to operate independently. Use of a honey comb configuration provides multiple ignitions before reloading new capsules.

Conclusion

Specific capabilities of PITCH may present advantages for cold start of combustors and ignition of different turbines:

It provides volumetric ignition by creating a jet of hot gases and burning particles within a wide range of parameters:



- 0.5-100 atm (7-1500 psi) of pressure
- 500-2000ºC temperature range
- The ignition delay (10-40 ms) and the burn duration (0.1-2 s) decreases with increased pressure
- Safe and reliable ignition for any combustible fuel mixture
- The low voltage (< 350 v) discharge in PITCH produces no electromagnetic interference and its operation is not affected by EMI or electrostatic discharge
- Use of multiple PITCH igniters greatly enhanced the chance of ignition of turbines
- The connecting tube delivers burning particles directly to the combustion zone, providing big advantages over conventional wall-mounted spark plugs
- PITCH offers a volumetric ignition, unlike point source igniters such as a spark plug, offering an increased chance of ignition for cold start and relight

Possible Areas of Future R&D

Making PITCH work for special application:

- High-pressure ignition of monopropellants, M315E as an example
- Modification of solid fuel mixtures (SFM) for control of ignition energy, burn duration, and burn properties
- Managing ignition transient effects through SFM formulation
- Effects of ambient oxygen on the photoignition process

Use of PITCH as an igniter for space/satellite applications:

- Study of long term stability of different SFM formulations in space environment
- Modification of SFM to prepare PITCH for application in a vacuum
- Control of ignition duration and burn properties for space vehicles
- Ruggedization of PITCH for long time survival in space environment
- A PITCH design with many ignition capsules and a few drive electronics

Photoignition agents as liquid fuel additives:

- Micro encapsulation of SFM in order to use it as an additive for liquid fuels
- Use of the above in specialized fuel injectors in order to achieve distributed ignition in larger rocket engines